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RESONANCE FREQUENCY OPTIMIZATION ALGORITHMS (QNA-ANN & PSO) FOR CIRCULAR PATCH ANTENNA

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ABSTRACT

In this paper a design of an performance analysis of FR-4 substrate for high frequency microstrip antenna and inset-fed dual frequency circular microstrip antenna rectangular slot for application in wireless communication and parasitically loaded CPW fed monopole antenna for broadband operation. The circular microstrip antenna resonates at 1.58 GHz and 2.43 GHz, which enables it's usage in the wireless communication domain such as in Wireless Local Area Network (WLAN).By varying the lengths of the rectangular slot, the proposed antenna can provide a tunable frequency ratio of 1.50 to 1.62 for the two operating frequency band. The performance of a low-profile coplanar waveguide (CPW)-fed monopole antenna comprising of a straight strip, a parasitic circular-hat patch, and a slotted CPW ground for broadband operation is presented.

A measured dual-frequency operation with a broad impedance bandwidth(10 dB return loss) of 77% from 3.4–7.62 GHz, covering the required bandwidths of the lower operating band of the Japan's ultra wideband (UWB), the 3.5/5.5 GHz WiMAX, and the 5.2/5.8 GHz WLAN standards, has finally been explored. Also, a stable monopole-like radiation pattern and an average antenna gain of 4.0 dBi across the operating band have been obtained. This work investigated the use of FR-4 substrate as a possible candidate for antenna design in the X-band has been designed at frequencies ranging from 2 to 10 GHz. For this purpose single element microstrip antennas have the variations in the antenna performance due to frequency increase have been studied. Co-axial probe fed circular microstrip antenna is a popular type of patch antenna having applications in communication and radar systems. Particle Swarm Optimization (PSO) is a popular optimization algorithm and recently it is being used for design optimization of microstrip patch antennas. In this paper PSO has been used for optimization of resonant frequency of coaxial probe fed circular microstrip antenna. Investigations are made for different design frequencies ranging between 5 GHz and 6 GHz. The optimization problem is treated as search over a space formed by two variables namely, patch radius and height of the substrate. The substrate material considered is PTFE, the commonest one used for this purpose. Results encourage the use of PSO for optimal design.

KEYWORDS: Co-Axial Probe Fed Circular Microstrip Antenna, Particle Swarm Optimization (PSO), Resonant Frequency, and Patch Radius, Microstrip Antenna, CPW, WiMAX

INTRODUCTION

Microstrip antennas have profound applications especially in the field of medical, military, mobile and satellite communications. Their utilization has become diverse because of their small size and light weight. Rapid and cost effective fabrication is especially important when it comes to the prototyping of antennas for their performance evaluation. As wireless applications require more and more bandwidth, the demand for wideband antennas operating at higher

frequencies becomes inevitable. Inherently microstrip antennas have narrow bandwidth and low efficiency and their performance greatly depends on the substrate parameters i.e. its dielectric constant, uniformity and loss tangent.

In this regard several comparative studies have been performed e.g. in an Current study investigated the use of FR-4 substrate for microstrip antennas at different frequencies (2, 4, 6, 8and 10GHz) The rationale behind this research was to study the FR-4 substrate as a possible candidate for the design of microstrip antenna array in X-band and to satisfy simulated and measured results in close approximation. FR-4 has been chosen for this study because of its low cost and convenient availability hence can be used for microstrip antenna array prototyping. Microstrip patch antennas are attractive for their well-known efficient features such as compatibility with monolithic microwave integrated circuits (MMIC), light weight, less fragile, low profile etc. The main disadvantage associated with microstrip patch antennas is the narrow bandwidth, which is due to the resonant characteristics of the patch structure. But on the other hand modern communication systems, such as those for wireless local area networks (WLAN), as well as emerging applications such as satellite links (vehicular, GPS,etc.) often require antennas with low cost and compactness, thus requiring planar technology. Due to the light weight of the microstrip patch antennas, they are appropriate for the systems to be mounted on the airborne platforms such as synthetic aperture radars (SAR) and scatter meters. Because of these applications of the microstrip patch antenna, a new motivation is evolved for research and development on indigenous solutions that overcome the bandwidth limitations of the patch antennas. In applications in which bandwidth enhancement is required for the operation of two separate sub bands, an appropriate alternative to the broadening of the total bandwidth is represented by dual-frequency microstrip antenna, which exhibits a dual-resonant behavior in a single radiating element. In this paper, a simple dual-frequency inset-fed circular microstrip antenna with a rectangular slot for the application in the WLAN is proposed. The radius of the antenna is 25 mm.

In this communication, considering a slotted patch antenna fed by a CPW structure can exhibit broad bandwidth, lower dispersion, lower radiation loss, and in particular can also easily be integrated with a broadband fiber optical system, a simple and low-profile broadband CPW-fed monopole antenna with a parasitic circular-hat patch and a slotted ground plane simultaneously suitable for the Japan's UWB lower band (3.4–4.8 GHz) operation, the 3.5/5.5 GHz(3.4–3.69 GHz/5.25–5.85 GHz) WiMAX operation, and the 5.2/5.8GHz (5.15–5.35 GHz/5.725–5.825 GHz) WLAN operation is proposed.

Though the proposed antenna was initially conceptualized from referring the prototypes reported in works, we found that with use of a further simplified slotted-ground structure in the proposed design, the antenna, comparing to the already reported antennas with the similar function can effectively provide not only a much wider impedance bandwidth but also a larger size reduction.

Microstrip Patch antennas are very popular nowadays because they are cheap, light weight and can be made conformal to the host body. Particle Swarm Optimization (PSO) has been introduced to the electromagnetic community for few years now for design optimization of patch antennas. In this paper PSO has been used for accurate determination of resonant frequency and return loss of circular probe-fed patch antenna. The investigation is made for different microwave frequencies ranging between 5 GHz to 6 GHz. The optimization problem has two variables namely, radius of the circular patch and height of the substrate respectively. Here a circular patch of radius 'a' is considered on a substrate of thickness 'H' and dielectric constant 'ε_r' for optimization. Feeding technique used is co-axial probe feed. The resonant frequency of operation of such antenna depends normally upon different parameters of the patch, dielectric and the probe. This paper presents a method for resonant frequency optimization of a circular microstrip patch antenna where the optimization

parameters are patch-radius and height of the substrate for Teflon (PTFE) substrate having dielectric constant 2.4 fed by a standard 50 ohm SMA co-axial connector.

Our aim is to design a circular microstrip antenna for operating with a desired resonant frequency. A PSO algorithm has been developed for obtaining the optimal values of antenna parameters. Initially search for the same starts from the approximate expression for resonant frequency given by equation (1).

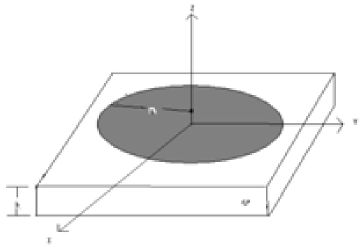

Figure 1: Circular Patch Antenna

PSO is a swarm intelligence based technique based on the movement and intelligence of swarms. Each element in the swarm is considered as an agent. Each agent has N-dimensional co-ordinates where each dimension corresponds to a parameter to be optimized. PSO requires less number of computations for optimization as compared to other evolutionary or random optimization techniques like Genetic Algorithms or Simulated Annealing etc.

ANTENNA STRUCTURE AND DESIGN

Shows the proposed antenna configuration. The basic antenna structure is a rectangle patch with dimensions (L×W) of printed on one side of a low-cost and easy-acquirement FR4 epoxy substrate with relative permittivity () 4.4 and substrate thickness 0.8 mm open-end circular ring slot and an inverted-U-shaped slot were embedded into the rectangle patch, and thus resemble the antenna structure as a CPW-fed strip monopole parasitically loaded with a circular-hat patch. Here, the used ring slot having an inner and an outer radius of ri and r0, respectively, was concentrically situated at the centre of the rectangle patch. The monopole element is a straight strip with dimensions of length Lf and width Wf, and has gap distances of d and s, respectively, to the ground and the circular-hat patch. For further improving the antenna's matching condition, two horizontal short slots with the same size of Ls×Ws were embedded into the ground's left and right inner edges at the centre position along the vertical direction. The moment method code, IE3D, was used for required numerical analysis to examine the performance of the proposed antenna configurations in terms of achieving the broad bandwidth. Via iterative trials, dimensions of the antenna with good broadband operation were finally obtained and tabulated in Table I. Note that for the feeding portion the strip width of Wf =2.2mm and gap distance of d=0.3mm were both obtained on leading to a characteristic impedance of 50 Ω, whereas the length Lf=15mm for the strip monopole was selected referring to the one-quarter wavelength of the desired operating frequency around 5 GHz.

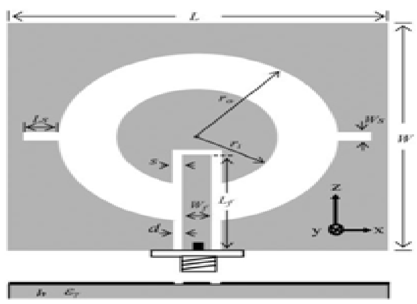

Figure 2: Geometry of the Proposed Broadband CPW-Fed Monopole Antenna with Parasitic Load

This section describes design methodology for a circular microstrip antenna. The generic antenna layout highlighting the main design parameters and dimensions, where R is the radius of the circular patch, FR is the radius where the desired input impedance is calculated, L is the length and W is the width of the feed line. The feed line is a quarter-wave transformer to match the input impedance of the patch to 50 ohm. The distance G between the radiating element edge and the ground edge is 0/4 according to [9].The commercially available FR-4 substrate was used in the antenna fabrication. These parameters are used in the design procedure for determining the radius and input impedance of the circular patch antenna.

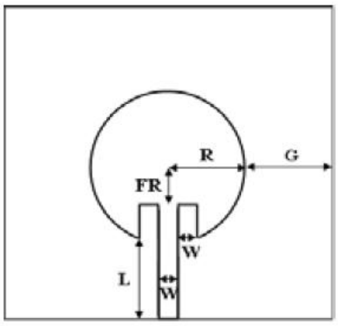

Figure 3: Side-Fed Circular Microstrip Patch Antenna

Where Fr is the resonance frequency in Hz,ξr is the substrate dielectric constant and h is the substrate thickness in cm. shows the geometry and configuration of a single frequency inset-fed circular microstrip antenna. The antenna (referred to as antenna 1 in this paper) was fabricated on an h=1.6 mm FR4 epoxy substrate with the dielectric constant εr=4.4 and loss tangent tanδ=0.002. As shown in the figure, a microstrip transmission line is used to feed the circular microstrip antenna. The feed is inserted deep into the circular radiating element for the proper impedance matching. This arrangement for the feeding a microstrip antenna is known as the “inset-feeding”. The electromagnetic software IE3D is employed to perform the design and optimization process. The design parameters are W=75 mm, L=80 mm, n =37 mm, g=1.0 mm, wf=3.05 mm and R=25. The inset length of the microstrip feed line is fixed at n=37 mm, which is 1.48 times (1.48R) of the radius of the circular microstrip antenna.

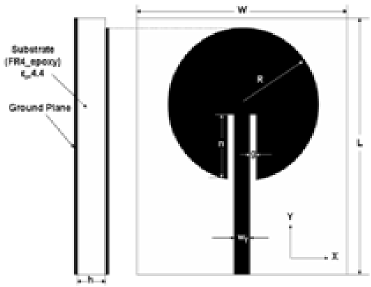

Figure 4: Geometry of Antenna

INITIAL DESIGN

The resonant frequency of a circular patch antenna is approximately given without considering the effect of probe radius by [1]:

$$F = (K_{nm} * c) / (2\pi a_e \sqrt{\varepsilon_r}) \tag{1}$$

Where a_e=effective radius of the circular patch

c= velocity of light in free space

ε_r = relative permittivity of the medium

K_{nm} = mth zero of the derivative of the Bessel function of order n.

In our application we have considered the fundamental mode TM_{11}, for which the value of K_{nm} is 1.84118. The expression for a_e is given by [2] as

$$a_e=a\{1+(2H/\pi a\varepsilon_r)[\ln(\pi a/2H)+1.7726]\}^{1/2} \quad (2)$$

Where H = height of the dielectric substrate

ε_r = relative permittivity of the medium

a = radius of the circular patch.

Once a circular patch antenna is designed this way for a desired frequency of operation, its dimensions can be chosen to form the initial search point wherefrom the optimal search begins. PSO is used thereafter to get an optimal design to achieve the given resonant frequency.

PARTICLE SWARM OPTIMIZATION TECHNIQUE

PSO is a robust stochastic evolutionary computation technique based on the principle of movement of swarms. [3-5] This technique has been applied for electromagnetic optimization recently. A swarm of bees flying in a field always try to find the location with the highest density of flowers. A bee starts from a random location with a random velocity. At each step the bee changes its velocity and position. Each position is represented by an N-dimensional co-ordinate system, where each dimension corresponds to a parameter to be optimized. The velocity and position of a particle can be determined from the following equations:

$$V_N = W*V_N + C_1\,\text{rand}(\,)*(P_{BEST,N} - X_N) + C_2\,\text{rand}(\,)*(G_{BEST} - X_N)$$

Where V_n is the velocity component of the particle in the N th dimension and X_N is the co-ordinate of the particle in that dimension. W is known as the 'internal weight' and its value is chosen to be between 0 and 1 which determines to what extent the particle remains along its original course unaffected by the pull of P_{BEST} and G_{BEST}. C_1 & C_2 are the scaling factors which determine the relative 'pull' of P_{BEST} and G_{BEST}. C_1 is a factor determining how much the particle is influenced by P_{BEST} and C_2 is a factor determining how the particle is influenced by the rest of the swarm. The random function 'rand' is introduced to incorporate the slight unpredictable component of natural swarm behaviour.

$$X_N = X_N + \Delta T*V_N \quad (3)$$

This equation updates the location of the particle for a given time step ΔT whose value may be chosen to be unity.

PSO BASED OPTIMIZATION OF RESONANT FREQUENCY

The objective of the work is to optimize the resonant frequency of a probe-fed circular patch antenna. The ranges selected for optimization of parameters are as follows:

Radius of the circular patch: 0.2 cm to 2 cm

Height of the substrate: upto (1/20)th of the wavelength of operation.

The cost function is defined as:

P= calculated resonant frequency – design frequency of operation|

When the calculated resonant frequency matches to its desired value, the value of the cost function P becomes zero ot negligibly small and the iterative search procedure stops. Otherwise it is stopped after a given maximum number of iterations.

For each particle a cost value is calculated which is the local best for the particle. This value is compared with the global best and if the any local best value is better than the global best the global best value is replaced by that local best.

RESULTS AND DISCUSSIONS

Investigations are made for five different microwave frequencies ranging from 5 GHz to 6 GHz.

The following table show results for the investigation for a maximum of 100 iterations in each case.

Table 1: Optimum Dimensions and Return Loss at Resonance

Design Frequency (in GHz)	Substrate Height 'H' (in cm)	Patch Radius 'a' (in cm)	Return Loss (in dB)
5	0.1530	1.0565	-23.5
5.25	0.1524	1.007	-41.9
5.5	0.1518	0.955	-25
5.75	0.1520	0.911	-26.5
6	0.1528	0.872	-52.8

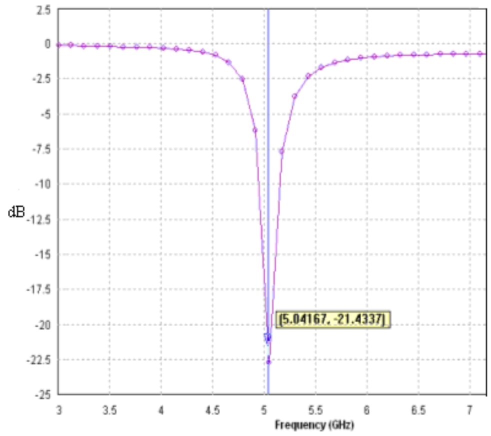

Figure 5: Return Loss vs Frequency Plot for Antenna Resonant at 5 GHz

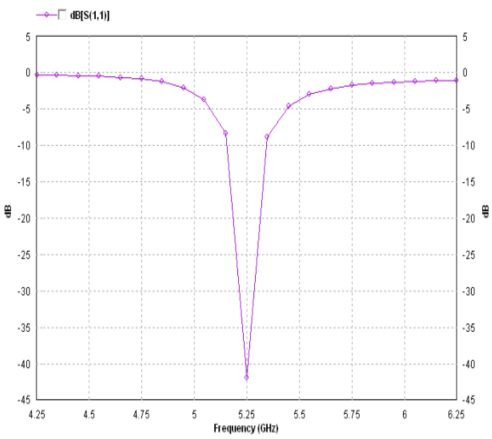

Figure 6: Return Loss vs Frequency Plot for Antenna Resonant at 5.25GHz

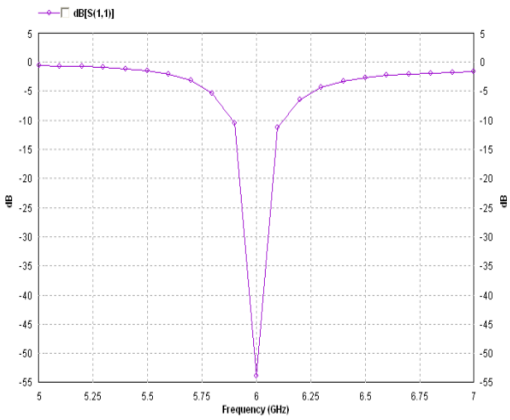

Figure 7: Return Loss Vs Frequency Plot for Antenna Resonant at 6 GHz

For all cases considered, the resonant frequency matches the design frequency exactly. Return loss plots for few such cases are shown in figures 5 – 7, obtained by numerical simulation using Method of Moments based commercial software IE3D.

CONCLUSIONS

On the basis of results obtained, it can be concluded that PSO can be efficiently used for optimization of different parameters of circular patch antenna. The advantage of PSO is its simplicity. The return loss plots show that the resonant frequencies obtained from the optimization process accurately match with the desired values with very small amount of return loss, which proves the efficiency of the method.

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